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## SPECIAL ARTICLES

THE TERTIARY FORMATIONS OF PORTO RICO<sup>1</sup>

IN 1914, the New York Academy of Sciences commenced a scientific survey of Porto Rico and the Virgin Islands. The outcome of this work has been a series of reports, covering geology and other branches of investigation. The important geological contributions which have been published are:

1. "A Geological Reconnaissance of Porto Rico," by C. P. Berkey, *Ann. N. Y. Acad. Sci.*, Vol. XXVI., pp. 1-70, 1915.

2. "Geology of the San Juan District," by D. R. Semmes, *N. Y. Acad. Sci., Sci. Surv. of P. R. and the Virgin Islands*, Vol. I., pt. 1, pp. 33-110, 1919.

In the summer of 1916, the writer, working under the auspices of the New York Academy of Sciences, made a detailed study of the northwestern portion of the island (Lares District). The results of that survey, together with the conclusions of Berkey, Semmes, and other geologists who have worked in Porto Rico, are outlined in the present paper.

*General Outline.*—R. T. Hill<sup>2</sup> showed that the central core of Porto Rico is made up of a volcanic complex, with sediments of Cretaceous age, and with coastal belts of a white limestone (Pepino Formation) of Tertiary age. In 1915, Berkey<sup>3</sup> showed that the central mountainous complex (Cretaceous) is overlain unconformably by the Tertiary limestones of the north and south coasts (Arecibo Formation). The Tertiary in turn is overlain disconformably by a limited coastal belt of solidified dune sands and beach deposits (San Juan Formation) of Pleistocene to Recent age. He called the Cretaceous complex the "Older Series"; the Tertiary and Pleistocene formations the "Younger Series," and pointed out that the unconformity separating these two series is a profound one,

<sup>1</sup> Presented before the Geological Society of America, Boston meeting, December 29-31, 1919.

<sup>2</sup> Porto Rico, *Nat. Geog. Mag.*, Vol. X., pp. 93-112, 1889.

the chief break in the geologic succession of the island. The work of Berkey, Semmes, and others has added much to our knowledge of the geologic structure of the island, especially of the Older Series rocks. However, the Younger Series is best developed in the northwest corner of the island, and it was not until work here had been completed that a detailed statement of the Tertiary formations could be made.

*The Tertiary Formations.*—The Tertiary formations are essentially a series of white limestones, part massive or reef-like, part well stratified. The beds are for the most part undisturbed, and dip gently seaward at angles of 4° to 6° on the north coast, and 10° or more on the south coast. Except locally, where slumping or slight warping has occurred, or faulting (on the south coast) these dips represent the initial angles at which the beds were deposited.

The Tertiary formations were laid down upon a slowly subsiding old land surface of considerable relief. The valleys of this old land surface were invaded by the sea during the initial submergence, and in them were deposited gravel, sand, mud, lignitic clay, and marl. Such deposits, with their alternation of fresh water, brackish water, and marine fossil faunas, now form the basal shale member of the Tertiary groups of the north and south coasts. Compared with the overlying limestones, this basal shale is local in distribution, and very variable in thickness.

The maximum thickness of the Tertiary group in the northwest part of the island (Lares District) is nearly 4,000 feet. On the south coast, Berkey<sup>4</sup> estimates the thickness at 3,000 to 4,000 feet. Evidence obtained in the Lares District seems to show that these beds were never deposited vertically to any such thickness, but are somewhat analogous to the fore-set beds of a delta. The limestones represent a series of fringing reefs whose maximum growth was outward rather than upward. It is believed that at the period of maximum submergence in Tertiary time, the central mountain chain of the island was not submerged. During sub-

mergence there was a progressive overlap from west to east. Thus in eastern Porto Rico and Vieques Island, the uppermost formation of the Tertiary group lies directly on the Cretaceous.

*Origin.*—These Tertiary limestones have been referred to as coral reef limestones. This is misleading, for while corals are abundant in the lowest reef limestone of the group, the overlying limestones are made up chiefly of foraminiferal and molluscan shells.

The so-called "Pepino" or "Haystack" hills (known as "Cock Pits" in Jamaica) are not individual reefs or reef-mounds, as might appear, but are the product of caving or slumping caused by an extensive underground drainage, aided by rapid surface solution. The result is a peculiar type of karst topography, seen on many of the islands of the West Indies, but nowhere so well developed as on the north coast of Porto Rico.

*Subdivisions.*—As a result of the work in the Lares District, the writer has made the following subdivisions of the Tertiary group of the north coast:

Arecibo Group	{	Quebradillas limestone—700–875 feet
	{	Los Puertos limestone—550–1,000 feet
	{	Cibao limestone—250–1,000 feet
	{	Lares formation—350–1,275 feet
	{	San Sebastian shale—max. 700 feet

In this classification, the names introduced by Berkey<sup>4</sup> have been used wherever possible. The term "Arecibo," introduced by Berkey, is used because the earlier name, "Pepino formation," of R. T. Hill is a purely lithological and topographical term, and is therefore undesirable.

On the south coast, no detailed subdivision has been made, but the names "Ponce" limestone and "Juana Diaz" shale (basal member) introduced by Berkey, are sufficient. After a careful study and comparison of a large collection of Tertiary fossils from the north and south coast formations, the following correlation is made, and believed to be essentially correct:

North Coast	South Coast
Quebradillas limestone Los Puertos limestone	Upper Ponce (including Guanica) limestone
Cibao limestone Lares formation	Lower Ponce limestone
San Sebastian shale	Juana Diaz shale

*Age.*—T. W. Vaughan,<sup>6</sup> from a study of fossil corals collected by R. T. Hill in the upper San Sebastian shale and lower Lares formation, concluded that the age of the "Pepino formation" is Middle Oligocene (Antiguan). C. J. Maury,<sup>7</sup> from a study of molluscan fossils collected in Porto Rico in 1914 by C. A. Reeds, concluded that the Quebradillas limestone is of Lower Miocene (Bowden) age, and that the "Rio Collazo shale" (= San Sebastian) is Middle Oligocene (Antiguan). The writer, from a study of a large collection of molluscan fossils from the Lares District, agrees with these conclusions, but would place the Quebradillas limestone (= Bowden) in the Upper Oligocene, rather than Lower Miocene. This departure seems to be warranted by the abundance of *Orthaulax* (several species) and *Ostrea antiguensis* throughout the Quebradillas. Furthermore, there is no faunal hiatus or disconformity to be found anywhere within the Tertiary group of the north coast. The entire series is a structural unit, as Berkey pointed out.<sup>8</sup>

The ages assigned to the north coast formations are as follows:

- |  |                     |
|--|---------------------|
| 7. San Juan formation.....             | Pleistocene-Recent  |
| .....                                  | Disconformity ..... |
| 6. Quebradillas limestone (= Bowden) } | Upper               |
| 5. Los Puertos limestone }             | Oligocene           |
| 4. Cibao limestone }                   | Middle              |
| 3. Lares formation }                   | Oligocene           |
| 2. San Sebastian shale }               | (Antiguan)          |
| .....                                  | Unconformity .....  |
| 1. Older Series .....                  | Upper Cretaceous    |

BELA HUBBARD

<sup>6</sup> Bull. 103 U. S. Nat. Mus., p. 260, 1919.

<sup>7</sup> *Am. Jour. Sci.*, Vol. XLVIII., p. 212, 1919.

<sup>8</sup> C. P. Berkey, *op. cit.*, p. 15.

<sup>4</sup> C. P. Berkey, *op. cit.*, p. 14.

<sup>5</sup> C. P. Berkey, *op. cit.*